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PROJECT APOLLO

SOME REDESIGNATION CHARACTERISTICS ATTRIBUTED TO SLOWING THE LM LANDING APPROACH TRAJECTORY

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Houston, Texas
May 30, 1969

SUMMARY

The recent slowdown of the operational trajectory has greatly affected the redesignation characteristics of the LM. The major effects are shown to be a forty percent reduction in redesignation ΔV-footprint and a reduction by at least a factor of five of the maximum downrange capability due to resulting trajectory shallowness. The possibility of eliminating these undesirable redesignation characteristics with a software change (delta guidance) is demonstrated.

INTRODUCTION

The LM descent trajectory has recently undergone the major change of slowing down the final approach to provide the velocities in the region of 300 to 500 ft altitude desired by astronauts. The object of this report is to show how this change has affected the landing site redesignation characteristics of the LM.

MIT has recently made a change to the LUMINARY program (a "K" term added to the guidance coordinate orientation routine) to decrease the guidance axes rotation associated with lateral redesignations--some of the effects of this new term are shown herein.

A few runs utilizing the previously reported "delta guidance logic" are presented to show the possibility of eliminating the undesirable redesignation characteristics.

TEST PLAN

The major characteristics of the two reference trajectories studied are shown on table I. The position and velocity conditions in guidance coordinates and the LPD angle are shown at four points on each trajectory; high gate, a range-to-go of 20,000 and 2000 ft, and at the end of the visibility phase (P64). The "1968" trajectory of reference 1 has high gate at 9800 ft altitude. The "1969" trajectory has high gate at 7300 ft, but the main differences in these trajectories are the final approach speeds--at 2000 ft range VZG has been lowered from 87 to 65 ft/sec. The 1969 trajectory requires 166 ft/sec more ΔV for an automatic landing, but with the new philosophy of budgeting the automatic to the area of manual takeover, the delta V's are the same on the two trajectories at a range of 2800 ft. The 1969 trajectory is not the latest reference trajectory at this time. Changes have occurred to account for a greater mass of the LM, but the final approach speeds (which is important in this study) will probably be about the same on the latest reference trajectory.

For each trajectory, using the EG27 all-digital LM descent program, redesignations were made at a range-to-go of 20,000 ft. Both forward and lateral redesignations of various magnitudes were instantaneously applied. One run of the test matrix was repeated using the vertical and horizontal delta guidance of reference 2.

DISCUSSION OF RESULTS

Cost of Redesignation

The capability of downrange and crossrange redesignation for a given ΔV (footprints) for both the 1968 and 1969 reference trajectories is shown on figure 1. The ΔV footprints are about 40 percent smaller for the new slower trajectory. The redesignation capability for the budgeted 60 ft/sec is only 2000 ft downrange--the minimum capability suggested in the constraints memorandum of reference 3 was 3000 ft.

Attitude for Out-of-Plane Redesignations

If redesignations are limited to the budgeted ΔV of 60 ft/sec, then the maximum terminal azimuth is about 40° and maximum bank angle is about 30°, as shown in figure 1b. The terminal azimuth angle would be the angle between the LM Z-body axis and the descent plane at touchdown. The maximum bank angle is the maximum angle encountered after the redesignation--bank (roll) was calculated from the standard aircraft attitude rotation sequence, pitch-roll-yaw. This angle does not correspond to any of the platform gimbal angles.

MIT has recently made a change in the LUMINARY program (PCN756) for the guidance coordinate orientation vector, as shown on figure 2a. The runs made for this report include that change with a value of 3/4 for the new gain term, except for the comparison shown on figure 2a with the old value of K = 1. This change was made to keep the terminal azimuth angle from getting large for lateral redesignation, which it does. But for redesignations within the 60 ft/sec budget, the K = 3/4 adds only another 200 ft lateral redesignation capbility, and saves about 5° of terminal azimuth.

Altitude Profile

The worst redesignation feature of the new trajectory is the resulting shallowness of the trajectory after redesignation. The contours of minimum approach angle, defined as the $\text{TAN}^{-1}(\frac{h}{RGO})$, is plotted on figure 2b

in the same fashion as the ΔV footprints. A comparison of 68 and 69 trajectories for just the downrange axis is shown on figure 2c. Data were not obtained for a crash condition ($\alpha = 0$), but the projection of the data available to $\alpha = 0$ suggests that 10,000 ft is the maximum possible redesignation with the 69 trajectory. A redesignation to 53,000 on the 68 trajectory was successfully made--the minimum α of $.1^{\circ}$ at 20,000 ft range to the new landing site suggests that 50,000 ft is the maximum possible redesignation with the 68 trajectory, or five times larger than the new trajectory.

For redesignations within the 60 ft/sec ΔV budget, the minimum approach angle for redesignations from a nominal trajectory is 11°. If off-nominal low conditions are encountered, then this number would be lower. This condition might be acceptable for Mission G; but for future missions, where a landing at a specific site is required, it appears necessary that something be done about the redesignation characteristics. One possible solution follows.

Redesignation Characteristics with Delta Guidance. - The delta guidance of reference 2 generates control laws, in addition to those presently used, to guide the vehicle back to a nominal trajectory. The trajectory shallowness resulting from redesignation is then removed, as shown on figure 3, by the "vertical delta guidance." Nominal horizontal approach speeds are also maintained with the "horizontal delta guidance" so that redesignations can be made efficiently. Note on figure 3 that a redesignation with delta guidance cost 28 ft/sec compared to 113 ft/sec without delta. The delta guidance run shown was flying the slow approach, 1969 trajectory.

CONCLUSIONS

The following conclusions result from the slower final approach trajectories being considered for LM descent.

a. The redesignation capability is about 40 percent lower; and the maximum redesignation capability, from approximately the earliest point of initiation of 20,000 ft range, is 2000 ft downrange (or 3800 ft crossrange) for the budgeted 60 ft/sec ΔV.

b. The additional "K" term added by MIT in the guidance coordinate orientation routine produces a minor improvement in ΔV and final approach angle for crossrange redesignations only.

c. The major problem of trajectory shallowness resulting from redesignations suggests that for Mission G, redesignations best remain within the 60 ft/sec ΔV budget.

d. For future missions to a specific landing site, a guidance "fix" such as suggested in reference 2 should be provided.

TABLE I. - SAMPLE POINTS ALONG TRAJECTORIES STUDIED

Trajectory	Time from Ignition t	-RZG	VZG	RXG	-VXG	LPD	V FTP to Touchdown	V FTP to RGØ = 2800 ft
1968 REF TRAJ	468	33400	569	9800	158	85 → 58	6570	6060
	496	20000	400	5800	116	54		
	576	2000	87	650	24	41		
	632.	2	1	78	3	87		
1969 REF TRAJ "Slower Final Approach"	464	26000	514	7300	133	71 → 64	6736	6060
	478	20000	409	5600	113	61		
	568	2000	65	513	16	30		
	634	56	5	150	3	72		

Note: Horizon visible from about t = 392, RZG = -84400, RXG = 17400 on 1969 traj, but not until after highgate on 1968 traj.

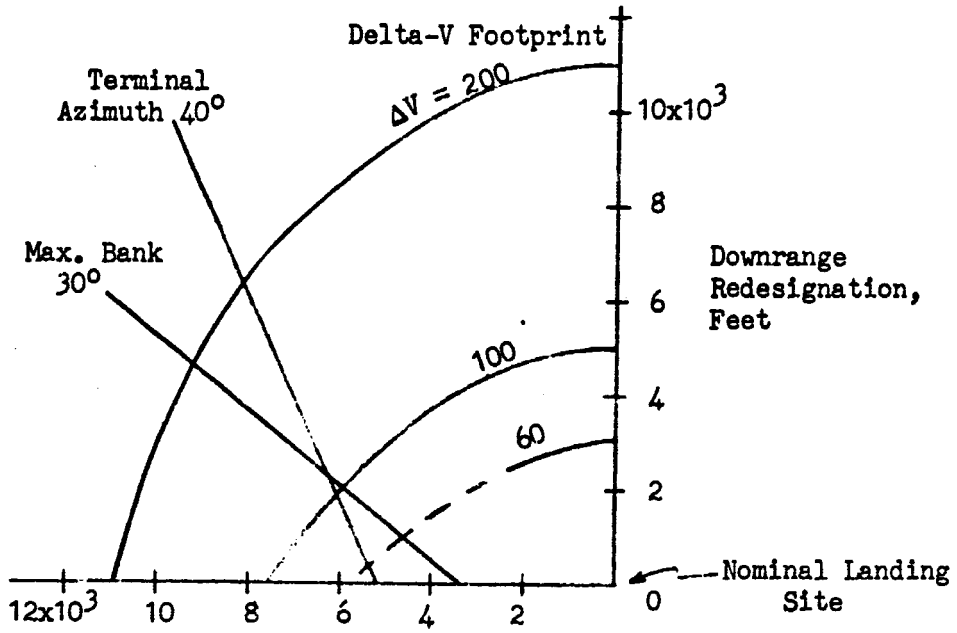

Fig 1a. - 1968 Ref. Traj.

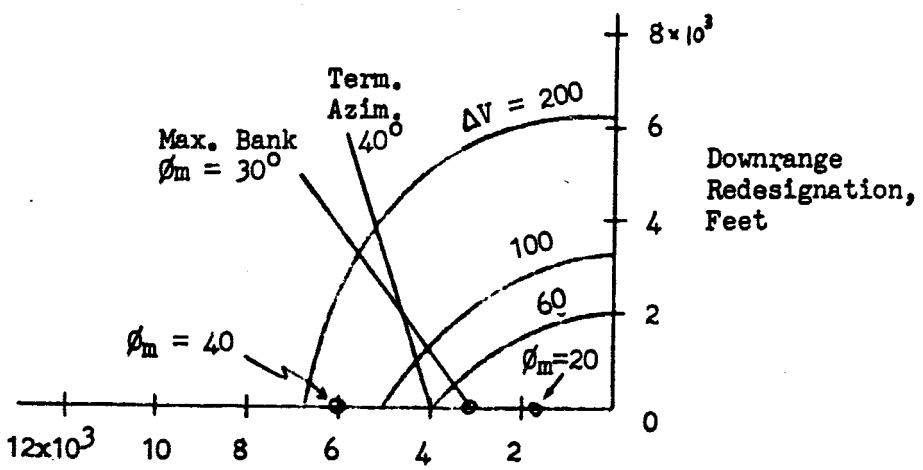

Fig 1b. - 1969 Ref. Traj. (K=3/4)

Figure 1. - Comparison of redesignation delta-V footprints for 1968 Ref. Trajectory and 1969 (slower final approach) Ref. Traj. redesignation made at 20,000 Ft. range to nominal landing site.

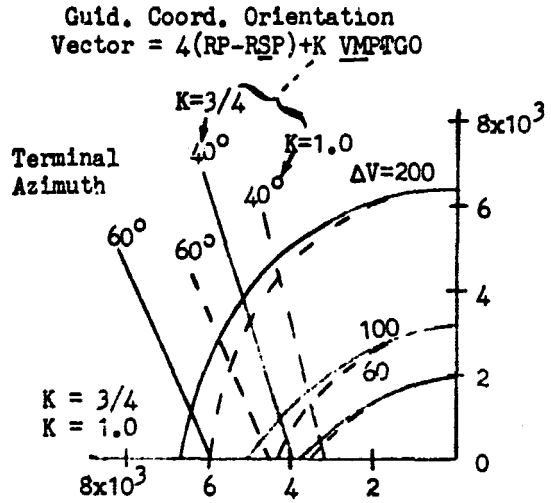

Fig. 2a-Effect of"K"

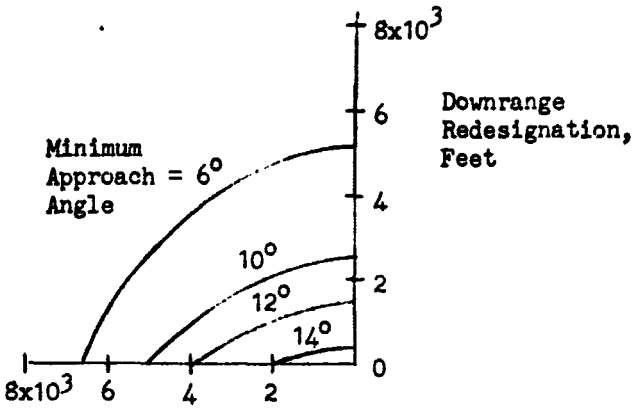

Fig. 2b - 1969 Ref. Traj.(K=3/4)

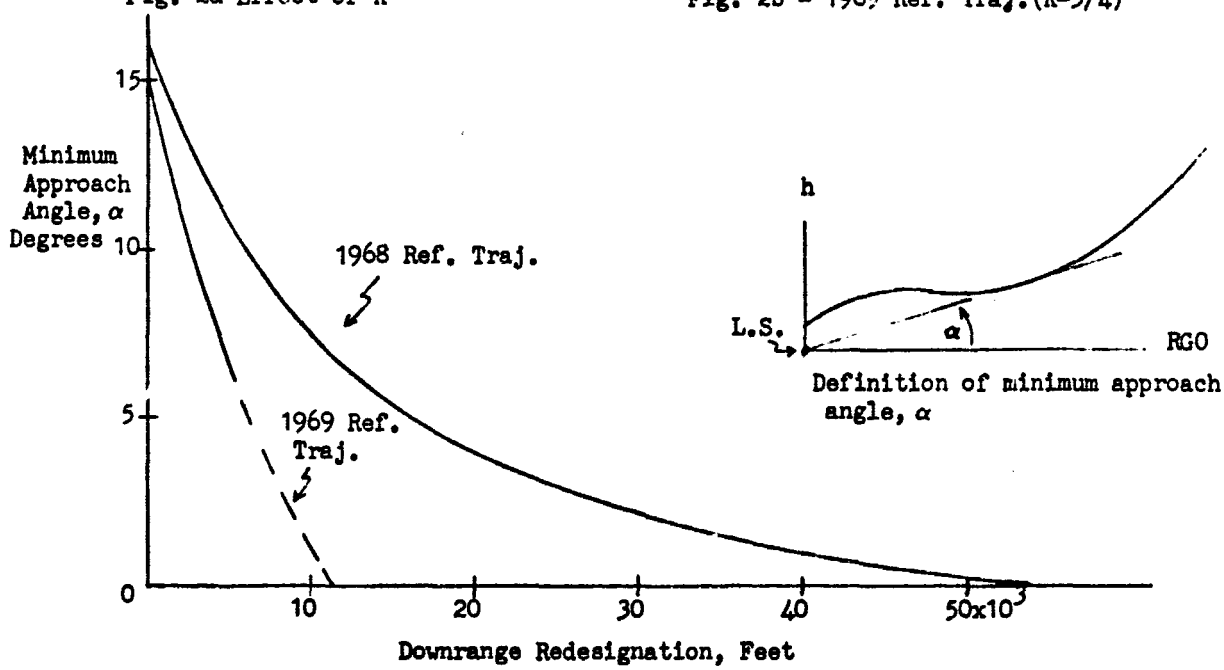

Figure 2c. - Comparison of minimum approach angles

Figure 2. - Effect of new "K" term in guidance coordinate axes orientation, and comparison of approach angles on the 1968 and 1969 Ref. Trajectories Redesignation at 20,000 Ft. range

	ΔV FTP to T.D.for 1969 Ref Traj	ΔV FTP to T.D. for 1969 Ref Traj w/Delta Guidance
Nominal	6736	6684
W/Redesignation	6849	6712
Cost Redes.	113	28

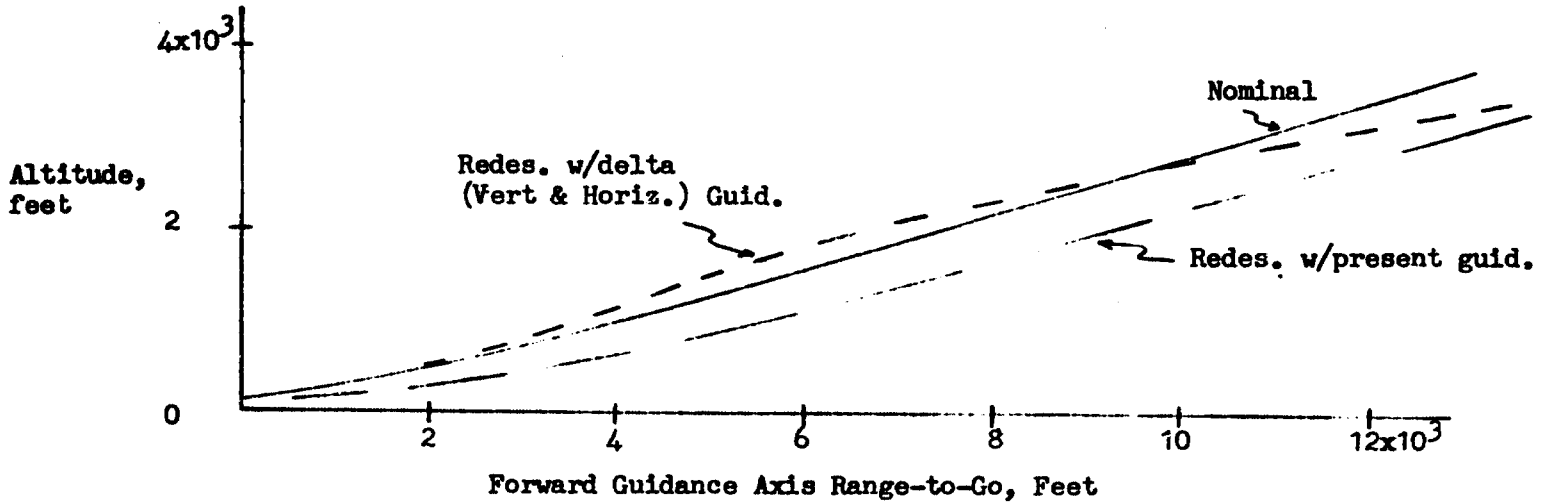

Figure 3. - Trajectories to a redesignated landing site 2875 Ft downrange and 2300 Ft crossrange (LPD input 2° FWD, 6° LAT @ RGO = 20000 FT) with present guidance logic and with present guidance logic plus delta guidance of reference

REFERENCES

1. Alphin, James H.; Taylor, Billy G.; and Kirkland, Burl G.: LM Powered Descent Trajectory for the Apollo Lunar Landing Mission. MSC Internal Note No. 68-FM-68, March 29, 1968.

2. Moore, Thomas E.; McSwain, Grady G.; and Montgomery, Jay D.: Guidance Laws for Controlling Off-Nominal LM Powered Descent Trajectories Back to the Nominal. MSC Internal Note No. EG-69-9, February 28, 1969.

3. Gardiner, Robert A.: LM Powered Descent Trajectory Constraints. MSC Memorandum EG27-277-68-1064, October 8, 1968.